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OVERALL EVALUATION OF ERTS IMAGERY FOR CARTOGRAPHIC APPLICATION

Alden P. Colvocoresses
U.S. Geological Survey
Washington, D.C. 20244

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Type I Progress Report
ERTS-A

a. Title: Overall Evaluation of ERTS Imagery for Cartographic Application

ERTS-A Proposal No.: MMC 233

b. GSFC ID No. of P.I.: IN 014

c. Problems: Obtaining cloud free coverage of sizeable areas under uniform conditions of illumination and response continues to be the major cartographic problem.

d. Accomplishments:

- A decision to develop ERTS image format maps has led to a prototype of a new type cartographic product. This prototype is named "Upper Chesapeake Bay" and is scheduled to be reproduced at 1:500,000 scale, in color, and placed on public sale during October. The concept will be described by me at the American Society of Photogrammetry Symposium to be held at Sioux Falls, S.D., Oct. 29 to Nov. 1, 1973.

- An update of a previous paper now titled "Unique Cartographic Characteristics of ERTS" has been prepared and approved for release (copy attached).

- A set of Requirements for Implementing Cartographic Application of an Operational ERTS Type Satellite has been prepared and is maintained based on the input from ERTS experiments. The latest version is dated Sept. 20, 1973, and a copy is attached.

- A working arrangement was developed with the Defense Mapping Agency wherein the Application of ERTS to aeronautical and nautical charting will be examined. NASA has agreed to obtain ERTS imagery of parts of the Caribbean and Gulf of Mexico where existing nautical charts are deficient. Existing coverage is planned for the aeronautical experiments - probably in Mexico or Central America.

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UNIQUE CARTOGRAPHIC CHARACTERISTICS OF ERTS*

October 1973

Alden P. Colvocoresses
U.S. Geological Survey
Washington, D.C. 20244

Aerial cameras and the photographs they produce have been increasingly applied to mapping and related studies for over 50 years. The manned spaceflights have demonstrated what film cameras can do in space, and cartographic cameras at orbital heights could provide a data source from which maps would be one of the principal products. ERTS was not defined with mapping as one of its principal objectives, but with ERTS-1 in orbit certain unique characteristics or advantages of the electronic transmission (TV) Earth-sensing system become apparent to the mapmaker. (Electronic transmission from geosynchronous orbit has characteristics completely different from either ERTS or film systems. This paper does not include any comparisons with geosynchronous Earth sensing.)

Eight of the more obvious advantages of ERTS-type sensing systems over aircraft and satellite film systems are as follows:

1. Long life and coverage. Even after 11 months of flying, a few areas of the U.S. are still not adequately covered by ERTS imagery suitable for cartographic purposes. Apparently a full year will be needed to complete the coverage even though the sensor is turned on for every pass over the U.S. That a single film-return satellite could be efficiently flown for such a long period, or come anywhere near complete U.S. coverage, is doubtful in the extreme. With luck, ERTS-1 may survive for 2 or more years and thus provide repetitive as well as complete coverage, making the most of only one launch, spacecraft, and instrument package.

2. Near real time. The advantage of electronic transmission in near real time is obvious even though the capability of realizing the advantages has not been fully developed. For example, a cartographic product was produced within 2 weeks after image acquisition by ERTS. Electronic transmission of imagery has, in the past, included sizable geometric distortions. ERTS is proving that imagery can be electronically transmitted without serious distortion.

3. Orthogonality. The field of view of the ERTS Multispectral Scanner (MSS) extends only 5.76° from the nominal vertical. The near orthogonality

*This paper updates and elaborates on a similar one titled "Unique Characteristics of ERTS" presented at the NASA Symposium on Significant Results Obtained from ERTS-1 New Carrollton, Maryland, March 6, 1973.

of ERTS imagery limits compilation of topographic (contour) maps but simplifies small-scale planimetric mapping and revision. Since topography changes little, maintaining up-to-date planimetry is the major mapping problem once an area has been topographically mapped. An image map, consisting of little more than an image precisely referenced to the figure of the Earth, is probably the most effective method of portraying up-to-date planimetry. ERTS imagery is ideal for small-scale image mapping for two reasons. First, external errors such as relief displacement are so small that the image can be used directly, except in areas of extreme relief, without going through the complex transformation provided by an analytical plotter or an orthophotoprinter. Second, the narrow field of view means that the entire scene is being imaged with a nearly constant vertical aspect and thus provides uniform spectral response from similar type objects throughout the scene.

4. Suitability for Planimetric Mapping. It is hard to conceive of an optical-mechanical scanner generating imagery which has the geometric fidelity of a frame camera. However the MSS scanner on ERTS is generating data that, as corrected by NASA, is printed out in a form that has spatial errors in the order of 50 m (rms). Since the scanner spot size (instantaneous field of view) is about 80 m, this indicates a system of high internal geometric fidelity. The 50 m (rms) error equals about 15 μm at the original MSS imagery scale of 1:3,369,000. 15 μm is a figure approaching that expected of a calibrated mapping camera. Whereas the internal geometric accuracy of the MSS may not be quite up to that of a good mapping camera, the accuracy it does have, when coupled with the external advantage of the near orthographic view, results in two dimensional (planimetric) mapping of geometric precision which may well exceed that obtainable from comparable camera systems.

5. Suitability for Automation. Frame cameras and vidicon imagers record discrete scenes. Each photograph or image frame has its own geometric characteristics, and unless extensive analytical adjustments are made, images in adjacent photographs will not fit together. A scanner such as the MSS produces a basically continuous image on a mathematically definable map projection of negligible distortion. Thus a means is established for relating the picture element (pixel) of the image to the figure of the Earth in a continuous and (within the limitations of the corrections) rigorous manner. These characteristics provide the potential for development of an automated image-mapping system by either analog or digital techniques with a significant decrease in requirements for ground control.

6. Radiometric fidelity. The ERTS signals, particularly those of the MSS, are in effect those of a focusing radiometer, recording radiated energy with a range and precision well beyond the capability of any current film system. Therefore, either on tape or as later recorded on

film, the spectral image of a given scene will be more meaningful from ERTS than from a film camera. Since ERTS records four wavebands, the images can be combined to provide a response optimized for particular scenes or for objects of sufficient size. Film cameras can record up to three bands on one film (color or color IR), but altering the combination for a particular scene or object is complex and imprecise. The separate band characteristic of ERTS is particularly important for mapping objects or areas that have unusual radiometric responses or that are imaged under unusual conditions of illumination, such as the polar regions.

7. <u>Extension into the near IR wavelengths</u>. Available aerial films cut off between 0.8 and 0.9 μm, which is about the same limit as for band 6 of the MSS. MSS band 7, at 0.8 to 1.1 μm, has opened a window for remote sensing which operational film systems do not have. The band is enormously powerful and has demonstrated the following unique capabilities:

a. Effective penetration of thin clouds and contrails (under certain conditions).

b. Definition of the water/land interface with high precision, enabling detection and identification of circular water bodies as small as 200 m diameter and linear water bodies of something less than 100 m width. Under suitable conditions, where gently sloping areas of known elevations exist, water stage can be determined to a fraction of a meter. The capability is particularly remarkable when one considers that the instantaneous field of view of the MSS (spot size) is 79 m.

c. Superior definition of vegetation patterns, largely due to the differential sensitivity of band 7 to vegetation types.

d. Superior definition of natural features. Geologists (and others) are selecting MSS 7 as the best single band for depicting the Earth's physiographic structure.

e. In some cases cultural features are best defined on band 7--for example, the pattern of major streets in western U.S. cities as so far recorded by ERTS.

Today television is an accepted means of visual communications, and electronic transmission Earth sensing systems, such as ERTS and its successors, promise to take their place beside the film camera as essential tools for cartography.

United States Department of the Interior

GEOLOGICAL SURVEY
WASHINGTON, D.C. 20242 4

JUL 26 1973

Memorandum

To: EROS Program Director

From: Chief, Topographic Division

Subject: PROGRAMS AND PLANS - Requirements for implementing cartographic applications of an operational ERTS-type satellite

It is understood that the Department of the Interior is developing the requirements for an operational ERTS-type satellite.

The Topographic Division has a vital interest in this activity, as there are potential cartographic applications of ERTS imagery which may be of considerable value to many mapping programs. The enclosed document provides technical requirements for implementing the cartographic applications. Certain requirements such as stereo coverage are not those of this Division but have been suggested by others involved in the mapping of foreign areas. These requirements have been tempered by what we understand to be the limitations imposed on an ERTS-type satellite in that it must conform to proven technology.

R. H. Lyddan

Enclosure

Note: In early September 1973, Interior (EROS) recognized that the thermal channel, though desirable, was probably not compatible with ERTS parameters. Therefore a minor modification was made to the attached on September 20, 1973, which eliminates the thermal band and retains the 4 MSS bands as presently defined.

Alden P. Colvocoresses
September 20, 1973

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9/20/73

Requirements for Implementing Cartographic Applications of An Operational ERTS Type Satellite

General

The cartographic community (foreign as well as domestic) has examined and evaluated ERTS-1 imagery. The consensus of the investigators is that an operational ERTS-type satellite can have many valuable mapping applications where the image itself may serve as the cartographic base for medium- and small-scale maps. The requirements for implementing these applications are based on capabilities as demonstrated by ERTS-1 or as defined for a future ERTS-type satellite as follows:

- o Continuous operation which, subject to visibility, covers the earth from 82° N to 82° S every 18 days.
- o Near-real-time reception of data.
- o Near orthogonal imagery (a maximum angle off axis of only 5.76°).
- o Geometric fidelity, which permits accurate mapping at scales as large as 1:250,000.
- o Spatial frequency (resolution) commensurate with instantaneous field of view in the 40- to 80-meter range.
- o Radiometric fidelity in several simultaneously acquired wavebands including the near infrared.

Spatial Frequency

Requirement - Image quality suitable for detection and identification of image control points and major planimetric features, such as roads, railroads, canals, field boundaries, urban boundaries, and water-land interfaces.

Rationale - Needed to produce meaningful photoimage maps at 1:250,000 scale, a standard medium scale accepted throughout the world. Much useful information for many disciplines can be derived from these products and referenced to the figure of the earth.

Present ERTS Performance - Instantaneous field of view (IFOV) of the MSS is a 79-m square and the recorded net pixel size is 79 by 59 m. The RBV line width is equivalent to 45 m and theoretically should produce the higher resolution, although empirical tests to date have not borne this out; the RBV is rated equivalent to the MSS with an effective pixel size of about 80 m.

Changes - To obtain the image quality required for more useful cartographic products, one band of imagery (0.6 - 0.7 μm) should have an effective pixel size of about half the side dimension of that of the present sensors.

Suggested Solution - Increase the focal length of the RBV, limit its response to one spectral band, and maintain the same width of coverage as the MSS. Considerable frequency increase can be obtained before image motion compensation (IMC), which is a complex modification, would be needed. Current criteria for acceptable image motion is that the degradation along track should not exceed 50% of the cross track resolution. The existing 79 m IFOV would be suitable for the MSS bands.

Spectral Frequency

Requirement - Record a minimum of two bands in the visible and two in the near IR.

Rationale - These spectral bands are needed to differentiate fixed and temporal phenomena, such as cultural features, open water, areas of vegetation cover, snow and ice, topographic features, local atmospheric anomalies, and the various meaningful variations and combinations of these phenomena insofar as unique recordable spectral responses exist.

Present ERTS Performance - Two visible and two near IR bands are now recorded by the MSS. The three RBV bands provide redundancy to the four MSS bands.

Changes - None

Temporal Frequency

Requirement - Near global coverage every 18 days.

Rationale - The frequency of repetitive coverage of ERTS-1, which promises to produce complete cloud-free coverage of the U.S. on an annual basis and coverage of selective representative areas on a seasonal or even monthly basis, is considered adequate except for monitoring short-lived phenomena. Increasing the number of satellites would increase frequency, but the cost of data acquisition and handling would probably negate this advantage. If short-lived phenomena are in fact to be monitored from space, a geosynchronous system capable of selective area coverage is believed to be the only feasible solution.

Present ERTS Performance - 18-day global coverage except for latitudes higher than 82°.

Changes - None

Geometric Properties of Imagery

Requirements - Capability to perform independent mapping at 1:1,000,000 scale to National Map Accuracy Standards (NMAS) and, with the benefit of ground control, at 1:250,000 scale to NMAS.

Rationale - An operational remote sensing system must not only record identifiable data but also have a means of spatial reference. An accepted system of reference is one that relates to the figure of the earth as described in spherical coordinates (lat/long) or plane coordinates (X Y). For mapping of remote areas, 1:1,000,000 scale is adequate for delineation and changes of gross features, but 1:250,000 scale is needed to portray changes to developed areas and indicate where more precise mapping is required. A 1:250,000-scale map that just meets NMAS contains errors of about 80 m (rms). Thus accuracy and MSS pixel size would be of the same approximate size, which is a logical relationship.

Present ERTS Performance - Mapping from ERTS data with control only by orbital and sensor parameters (independent mapping) involves errors in the order of 2,000 m (rms). This is compatible with maps of 1:6,000,000 scale. With the aid of ground control, a system-corrected (bulk) image when fitted to a conventional map projection involves errors of 200-450 m, which is marginal with respect to 1:1,000,000-scale mapping. Fitting a geodetic grid to an MSS image, reduces errors to the 50 to 100 m range, which is compatible with 1:250,000-scale mapping. However this involves the use of the existing projection of the MSS image which is semiperspective and lacks the conformality of geodetic projections. Scene-corrected (precision processed) MSS imagery has errors in the 100- to 200-m range but because of degraded image quality is considered suitable for mapping at no larger than 1:500,000 or possibly 1:1,000,000 scale. On a portion (1/16) of an MSS image on which at least two control points can be identified, points which are part of a defined pattern (shore line, field lines, highways, etc.) can be located to within 20 to 30m(like all other accuracy figures stated herein these are rms figures).

Changes - Increase the independent mapping capability from 1:6,000,000 (2,000 m) to 1:1,000,000 scale (300 m) if possible. Where suitable ground control exists, lower the errors of the scene-corrected (precision-processed)*image to less than 80 m and retain the quality of the system-corrected image.

Suggested Solution - Improve positional and attitude determination devices. Modify the system corrected (bulk) printing of MSS to a conformal (Space Oblique Mercator) projection. Modify the scene-corrected system so that the image is derived from the original tape but still cast on a conventional (UTM) projection* and incorporates the marginal data of the present scene-corrected

*Since the Space Oblique Mercator and UTM projections are of a similar form, it may be preferable to fit the UTM grid to the Space Oblique Mercator rather than recast the image on the UTM.

system. Incorporate one RBV band with maximum spatial frequency and an engineered reseau.

Image Repeatability

Requirement - Hold successive images of the same scene to ±10 km or preferably ±5 km as the maximum deviation from the nominal scene center.

Rationale - An ERTS satellite system has the potential of repeating image positions to the indicated requirements. If accomplished, this would provide a worldwide system of map formats based on the nominal scene with very high assurance that the formats will be completely covered by subsequent corresponding scenes. Such maps could be published in perhaps 1/10 the time and effort now required for mapping on conventional formats, which normally involve images from several orbital passes. Use of the image format would permit publication and distribution of ERTS imagery in a timely and relatively inexpensive form.

Present ERTS Performance - The ERTS orbit is permitted to drift (cross-track direction) about ±15 km before corrections are made. Along-track image boundaries are generally within ±5 km.

Changes - Hold orbital drift, attitude variation, and along-track image boundaries of the MSS so that the resultant scene has an allowable deviation of ±10 km, or preferably ±5 km, from a prescribed center point.

Suggested Solution - Increase frequency of orbital and attitude corrections and improve standards for defining along-track image boundaries of the MSS.

Stereo Coverage*

Requirement - Once-over stereo coverage of the mountainous areas of the earth.

Rationale - The stereo mode assists features delineation and identification. In unmapped areas, gross elevation differences are needed and can be provided by stereo coverage with a 0.2 to 0.4 base-height ratio. This permits contouring in the 100- to 300-m range.

Present Performance - Stereo is limited to the sidelap of MSS, which is minimal in the lower latitudes and always has less than 0.2 base-height ratio, and to the narrow forward lap of the RBV.

Changes - Obtain stereo coverage of 0.2 or 0.4 base-height ratio of sizeable parts of the world.

Suggested Solution - Tilt spacecraft fore or aft 10.5° or 20° for several cycles until oblique imagery is obtained for most of the mountainous areas of the earth. Such oblique imagery when used in conjunction with vertical imagery will provide required stereo coverage.

Sensor Alignment

Requirement - Obtain a square MSS image format at the midlatitudes.

Rationale - Scanners and frame images should cover the same area. A square format is the more efficient to process and also is more esthetic.

Present Performance - MSS has a 3° nominal image skew at the midlatitudes-- 4° at the equator and 0° at maximum inclination (81°).

*This is a general rather than cartographic requirement but its incorporation will increase the cartographic utility of ERTS.

Changes - Define a nominally square image for the MSS at the midlatitudes.

Suggested Solution - Turn the spacecraft or sensors 3° to the right of the spacecraft velocity vector. This will create 1° skew at the equator, near 0° at the midlatitudes on the descending node, and 3° at the maximum inclination (82°) where it is of lessor concern.

CARTOGRAPHIC REQUIREMENTS FOR AN OPERATIONAL ERTS TYPE SATELLITE

REQUIREMENTS	RATIONALE	PRESENT PERFORMANCE	CHANGES AND SUGGESTED SOLUTION
Spatial Frequency 1 band 40 m pixel 4 band 80 m IFOV	Identification of key cultural features. Image maps of 1:250,000 to 1:1,000,000 scale	80 m effective pixel size (RBV) 80 m IFOV (MSS)	Increase focal length of RBV and reduce to one band.
Spectral Frequency 2 bands in visible 2 band in near IR, MSS 1 redundant RBV band (in visible)	Differentiation of fixed and temporal phenomena	2 bands in visible 2 bands in near IR 3 RBV bands redundant to MSS	Reduce RBV bands to 1
Temporal Frequency Near global coverage every 18 days.	Optimum for this type of satellite system. ERTS orbit unsuited for detection of short-lived phenomena	Coverage every 18 days between N 82° and S 82°	No change
Geometry of Image Capable of 1:1,000,000-scale independent mapping; capable of 1:250,000-scale mapping with control (all at NMAS)	1:1,000,000 is adequate for delineation of gross features and change thereto. 1:250,000 scale is needed to portray changes in developed areas and indicate where precise mapping is required.	Capable of independent mapping at 1:6,000,000 scale. With control image can be fitted to 1:1,000,000 scale map. Grid can be fitted to image of 1:250,000 scale. Scene corrected imagery is suited for 1:500,000 or 1:1,000,000 scale mapping.	Improve positional ar attitude determination to $\pm$ 300 m (rms). Convert bulk image to conformal projection. Improve scene corrected processing to retai original image quality. Use one RBV band of increas spatial frequency AN engineered reseau.
Image Repeatability Hold successive images of the same scene to $\pm$ 10 km or preferably $\pm$5 km of nominal scene center.	The image format when repeated within stated limits becomes the basis for mapping; it would involve perhaps 1/10 the time and effort of conventional quadrangle mapping.	Orbit drift involves $\pm$15 km across track; image boundaries are within $\pm$5 km along track	Hold orbital drift, attitude and along-track image boundar so that scene is held to $\pm$10 km or preferably $\pm$5 km of designated center. Use same nominal nadir points as for ERTS-1.

REQUIREMENTS	RATIONALE	PRESENT PERFORMANCE	CHANGES AND SUGGESTED SOLUTION
<u>Stereo Coverage</u>* Once-over stereo coverage of mountainous areas.	The stereo mode assists feature delineation and identification. In unmapped area, gross elevation differences are needed, and are provided by stereo coverage. Contouring in the 100 to 300 m range would be possible.	Stereo is limited to the sidelap of MSS plus the small forward lap of the RBV's.	Tilt the spacecraft ~~[illegible]~~ 10.5° or 20° ~~fo~~ fa or aft and leave i this position unti adequate coverage is obtained. ~~Ste~~ Ster will result when combined with vertical coverage.
<u>Sensor Alignment</u> Nominal square format for MSS.	Same coverage as RBV is needed. Square format is more efficient and esthetic.	MSS has 3° nominal skew at midlatitudes.	Skew spacecraft or sensors 3° to the right of the spacecraft velocity vector.

*Desirable but not required